

## ANDROMEDA XVII: A NEW LOW-LUMINOSITY SATELLITE OF M31

M. J. IRWIN,<sup>1</sup> A. M. N. FERGUSON,<sup>2</sup> A. P. HUXOR,<sup>2</sup> N. R. TANVIR,<sup>3</sup> R. A. IBATA,<sup>4</sup> AND G. F. LEWIS<sup>5</sup>

*Received 2008 January 23; accepted 2008 February 6; published 2008 March 4*

### ABSTRACT

We report the discovery of a new dwarf spheroidal galaxy near M31 on the basis of INT/WFC imaging. The system, Andromeda XVII (And XVII), is located at a projected radius of  $\approx 44$  kpc from M31, has a line-of-sight distance of  $794 \pm 40$  kpc measured using the tip of the red giant branch, and therefore lies well within the halo of M31. The color of the red giant branch implies a metallicity of  $[\text{Fe}/\text{H}] \approx -1.9$ , and we find an absolute magnitude of  $M_V \approx -8.5$ . Three globular clusters lie near the main body of And XVII, suggesting a possible association; if any of these are confirmed, it would make And XVII exceptionally unusual among the faint dSph population. The projected position on the sky of And XVII strengthens an intriguing alignment apparent in the satellite system of M31, although with a caveat about biases stemming from the current area surveyed to significant depth.

*Subject headings:* galaxies: dwarf — galaxies: halos — galaxies: individual (M31) — globular clusters: general

*Online material:* color figures

### 1. INTRODUCTION

The new generation of sensitive wide-field surveys has been rapidly improving our knowledge of the satellite systems of the Milky Way and M31. These surveys not only are uncovering increasing levels of complexity in the known dwarf spheroidal (dSph) population (e.g., Komiyama et al. 2007; McConnachie et al. 2007) but are discovering many new low surface brightness members of both systems. In the case of the Milky Way, 14 new satellites have been reported in the last few years, more than doubling the number of known and revealing a few systems with properties more suggestive of extended star clusters than dwarf galaxies (e.g., Willman et al. 2005a, 2005b; Belokurov et al. 2006; Sakamoto & Hasegawa 2006; Zucker et al. 2006a, 2006b; Belokurov et al. 2007; Koposov et al. 2007; Walsh et al. 2007; Irwin et al. 2007). Progress has been similarly rapid for the M31 system, building on the pioneering visual survey of van den Bergh (1972); the number of known dSph systems has increased in recent years from six to 14, with the nature of one system (And VIII) still under dispute (Morrison et al. 2003) while a further candidate system, And IV, has been conclusively shown to be a background galaxy (Ferguson et al. 2000).

Modern-day M31 dSph discoveries have mainly come from a few panoramic digital surveys. This era began with Armandroff et al. (1998, 1999) and Karachentsev & Karachentseva (1999) using digitized POSS plates to discover And V, VI, and VII. The SDSS survey led to the discovery of And IX and X (Zucker et al. 2004, 2007). A MegaCam CFHT survey uncovered And XI, XII, XIII, XV, and XVI (Martin et al. 2006; Ibata et al. 2007), while And XIV came from a survey of the outermost part of the southeast halo (Majewski et al. 2007). With each new area surveyed, more dwarfs are being uncovered, and it seems a complete census of both M31 and the Milky

Way will contribute to a resolution of the missing satellite problem (e.g., Simon & Geha 2007).

We present here the discovery of a new dSph found in the course of an extension of the INT/WFC imaging survey, previously described in Ferguson et al. (2002) and Irwin et al. (2005). Throughout this Letter we assume a distance to M31 of 785 kpc (McConnachie et al. 2005).

### 2. OBSERVATIONS AND DISCOVERY

For several years, we have been using the Isaac Newton 2.5 m Telescope equipped with the Wide Field Camera (INT/WFC) to conduct an imaging survey of M31 and the surrounding environment within a projected radius of  $\approx 60$  kpc (Ibata et al. 2001; Ferguson et al. 2002; Irwin et al. 2005; Huxor et al. 2008). Observations are taken in the Johnson *V* and Gunn *i* filters with exposures in the range of 800–1200 s. Under typical seeing conditions of  $1.0''$ – $1.2''$ , this is sufficient to detect individual stars at the distance of M31 to  $\approx 3$  mag below the tip of the red giant branch (RGB). The images are processed using the Cambridge Astronomical Survey Unit (CASU) pipeline (Irwin & Lewis 2001) following the procedure outlined in Ferguson et al. (2002) and Irwin et al. (2005). To date, some 200 contiguous fields have been targeted, covering approximately  $50 \text{ deg}^2$  of sky centered on M31, which at that distance corresponds to a projected surface area of  $\approx 100 \times 100$  kpc.

The photometric calibration of the survey is based on a combination of standard stars (Landolt 1992) observed on photometric nights and the  $\approx 10\%$  overlap between adjacent pointings. Color equations defining the transformation between Landolt photometry and instrumental *V* and *i* magnitudes are given in McConnachie et al. (2004). Extinction-corrected values are based on the Schlegel et al. (1998) extinction maps together with the extinction coefficients defined therein. Although the average value of the extinction in this direction is quite low,  $E(B - V) = 0.075$ , the foreground extinction varies sufficiently to warrant star-by-star correction as a function of field position, and this has been applied to the photometry reported in this Letter.

The new stellar system was discovered in data taken as part of a northern extension to the INT survey, carried out during 2005 September 23–29. Although the stellar concentration is just visible on the *V*- and *i*-band images (see Fig. 1), the system

<sup>1</sup> Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK.

<sup>2</sup> Institute for Astronomy, University of Edinburgh, Royal Observatory, Blackford Hill, Edinburgh EH9 3HJ, UK.

<sup>3</sup> Department of Physics and Astronomy, University of Leicester, Leicester LE1 7RH, UK.

<sup>4</sup> Observatoire de Strasbourg, 11 rue de l'Université, F-67000 Strasbourg, France.

<sup>5</sup> Institute of Astronomy, School of Physics, A29, University of Sydney, NSW 2006, Australia.

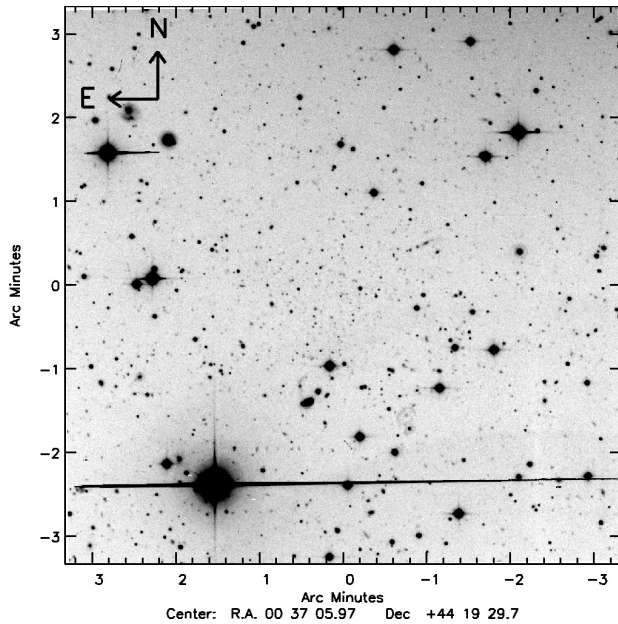


FIG. 1.—INT/WFC V-band image centered on And XVII. North is to the top and east to the left. The image spans  $\sim 6.5'$  on a side. The 5th magnitude foreground star HD 3346 lies  $\sim 10'$  to the north on the adjacent detector, and scattered light from this causes the background gradient seen in the figure.

is readily seen on a map of stellar sources with magnitudes and colors appropriate for metal-poor RGB stars at the distance of M31 (Fig. 2). As we will discuss, the properties of this system are consistent with its being a dSph galaxy, and we thus follow the naming convention originally devised by van den Bergh (1972) and refer to it as Andromeda XVII (And XVII). Located at  $(\alpha, \delta)_{J2000} \approx (00^h37^m07^s, 44^\circ19'20'')$ , And XVII lies at a projected distance of  $3.2^\circ$  from the center of M31, making it, in projection, one of the innermost known members of the satellite system.

We note that although this is a relatively bright satellite (see Table 1) located in quite a low-density region around M31, the proximity of the 5th magnitude star HD 344, and its associated scattered light, would have made detection on earlier photographic data quite difficult. It is therefore unsurprising that discovery of such a system required the advent of wide-field digital surveys.

### 3. THE PROPERTIES OF AND XVII

The derived properties of And XVII are summarized in Table 1. Figure 2 shows a contour map of a  $0.5^\circ \times 0.5^\circ$  region centered on the location of And XVII for all stellar objects with magnitudes and colors consistent with metal-poor RGB stars at the distance of M31. The overdensity corresponding to the dwarf is well defined and clearly separated from both foreground and M31 background components. The contour map was constructed by binning the distribution into  $14''$  pixels and then smoothing with a Gaussian kernel of  $\text{FWHM} = 70''$ . And XVII is clearly extended along roughly an E-W direction with a measured average overall ellipticity of  $\sim 0.2$ . In the outer regions, the contours become significantly more elongated, possibly indicative of tidal effects, but given the small number of stars in these regions, deeper observations are required to confirm this behavior and examine their overall extent.

The tip of the RGB is a standard candle in old, low-metallicity systems and thus can be used to estimate the line-of-sight distance to the dwarf. Although sparsely populated, the lu-

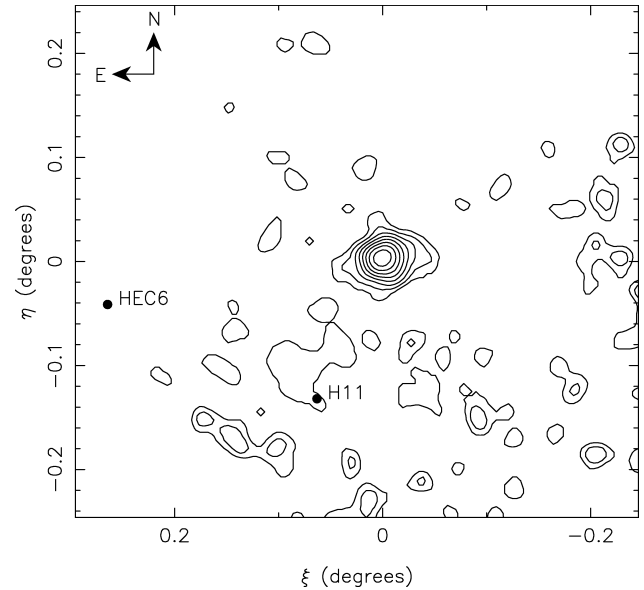


FIG. 2.—Contour map of the distribution of stellar objects with magnitudes and colors consistent with metal-poor RGB stars at the distance of M31 with the positions of the nearby outer clusters H11 and HEC 6 indicated. The distribution has been binned into  $14''$  pixels and then smoothed with a Gaussian kernel of  $\text{FWHM} 70''$ . The first two contour levels are  $\approx 2\sigma$  and  $3\sigma$  and then increase at progressively larger increments to maintain visibility of the central regions of the dwarf. The blank region to the top right is caused by the heavily saturated 5th magnitude star HD 344.

minosity function (LF) of RGB stars in the vicinity of And XVII shows clear evidence for a discontinuity at  $I_0 \sim 20.5 \pm 0.1$  (see Fig. 3). Assuming  $M_V(\text{TRGB}) = -4.04$  (Bellazzini et al. 2001; McConnachie et al. 2005) over the applicable metallicity range, this leads to a distance modulus of  $(m - M)_0 = 24.5 \pm 0.1$  ( $D = 794 \pm 40$  kpc). To within the errors, And XVII therefore lies at the same distance as M31. Because of background gradients induced by the nearby star HD344, the luminosity of And XVII proved impossible to derive reliably by direct integration. We therefore opted to compare the upper RGB LF with that of And V and And IX, which we had also imaged on the INT/WFC using the same setup. Making the plausible assumption of similar stellar populations for the three systems, direct comparison of the derived LFs yields an estimate of the relative luminosity of And XVII to be  $M_V \sim -8.5$ , i.e., of comparable luminosity to And IX but roughly 1 mag fainter than And V.

Figure 3 shows dereddened color-magnitude diagrams (CMDs) of stellar sources lying within an ellipse of semimajor

TABLE 1  
PROPERTIES OF AND XVII

Parameter <sup>a</sup>	Value
Coordinates (J2000.0) .....	$00^h37^m07.0^s, 44^\circ19'20''$
Coordinates (Galactic) .....	$l = 120.23^\circ, b = -18.47^\circ$
Position angle .....	$\approx 103^\circ$
Ellipticity .....	$\approx 0.2$
$r_h$ (Plummer) .....	$1.1' \pm 0.1'$
$A_V$ .....	$0.246^m$
$\mu_{0,V}$ (Plummer) .....	$26.1^m$
$V_{\text{tot}}$ .....	$16.0^m$
$(m - M)_0$ .....	$24.5^m$
$M_{\text{tot},V}$ .....	$-8.5^m$

<sup>a</sup> Surface brightnesses and integrated magnitudes are accurate to  $\pm 0.5$  mag and are corrected for the mean Galactic foreground reddening,  $A_V$ , shown.

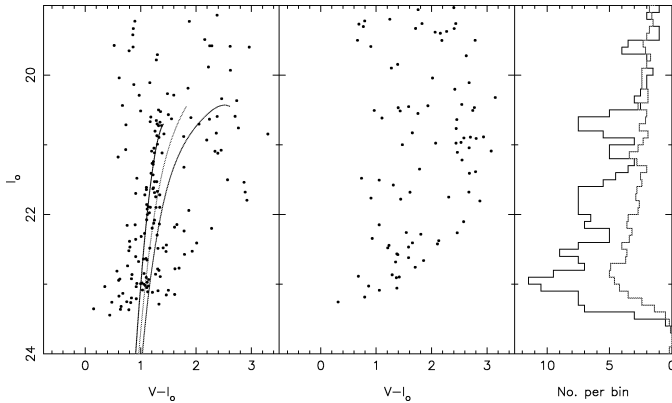


FIG. 3.—*Left and center panels:* Extinction-corrected CMDs of stars within an elliptical region ( $a = 2.5'$ ,  $e = 0.2$ , and P.A. =  $103^\circ$ ) centered on And XVII (*left*) and a nearby comparison region covering the same area (*center*). Overlaid on the And XVII CMDs are isochrones corresponding to 47 Tuc ([Fe/H] =  $-0.7$ ), NGC 1851 ([Fe/H] =  $-1.3$ ), and NGC 6397 ([Fe/H] =  $-1.9$ ). *Right panel:* I-band LF of the region centered on And XVII compared to an offset region covering 5 times the area and renormalized appropriately. [See the electronic edition of the *Journal* for a color version of this figure.]

axis of  $2.5'$ , ellipticity of  $0.2$ , and position angle (P.A.) of  $103^\circ$  centered on And XVII and of stellar sources in a nearby comparison region of the same area. A clear RGB sequence is apparent in the region coincident with And XVII, but there is no evidence for any young main-sequence population. Globular cluster fiducials of metallicity [Fe/H] =  $-0.71$  (47 Tuc),  $-1.29$  (NGC 1851), and  $-1.91$  (NGC 6397) are overlaid, and it can be seen that the system is metal poor, with a metallicity best matched by NGC 6397.

The background-corrected radial profile of And XVII was calculated in elliptical annuli with P.A. and ellipticity held constant at the values given in Table 1 and is shown in Figure 4. The background level of  $0.9 \pm 0.1$  stars arcmin $^{-2}$  was derived from the asymptotic level attained in the outer parts. The error from this is added in quadrature to the Poisson count uncertainty to give the error bars shown in the figure.

Overplotted are fits to a Plummer law and an exponential profile, yielding scale lengths of  $1.1'$  (250 pc) and  $0.65'$  (150 pc), respectively. These equate to half-light radii of  $1.1'$  (250 pc) in both cases. The integral of the profile defined by the Plummer model, coupled with our estimate of the absolute magnitude of this system, defines the peak brightness in the Plummer model and implies an extinction-corrected central surface brightness of  $\mu_{0,V} \sim 26.1$  mag arcsec $^{-2}$ . Both Plummer and exponential fits provide a reasonably good match to the observed stellar profile to  $\sim 3'$ , beyond which the star counts may flatten (see Fig. 4). Although background uncertainties could be partly responsible for this behavior, such profile flattenings are often seen at large radii in dSphs and could also result from a population of extratidal stars (e.g., Irwin & Hatzidimitriou 1995; Choi et al. 2002).

#### 4. DISCUSSION

The overall properties we have derived for And XVII are not unusual when compared to those of other recently discovered satellites of M31 and the Milky Way. Although of low luminosity, And XVII is  $\sim 4$ – $6$  times more luminous than the ultrafaint M31 dSphs discovered by Martin et al. (2006). Furthermore, the metallicity of And XVII is consistent with that of similarly luminous M31 dSphs (e.g., And IX, And X, and And XIV [Zucker et al. 2004, 2007; Majewski et al. 2007]).

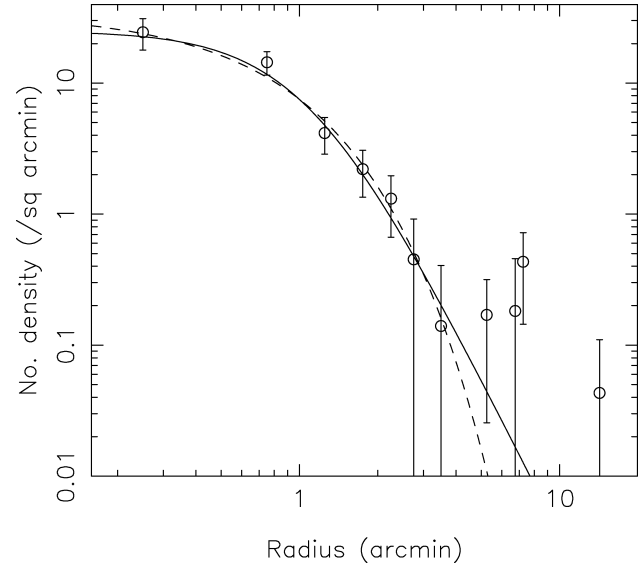


FIG. 4.—Background-corrected radial profile of And XVII calculated from elliptical aperture photometry ( $e = 0.2$  and P.A. =  $103^\circ$ ). A background level of  $0.9$  stars arcmin $^{-2}$  is used. Overplotted are Plummer law (solid line) and exponential (dashed line) fits with scale lengths of  $1.1'$  and  $0.65'$ , respectively.

There are, however, two properties of And XVII that are of further note. First, quite unusually, there are three recently discovered globular clusters (GCs) that lie close to the main body of And XVII. The projected distances to H11, HEC 6, and HEC 3 are  $8.8'$  (2 kpc),  $16.1'$  (3.7 kpc), and  $25.7'$  (5.9 kpc), respectively (Huxor et al. 2008). While H11 is a classical GC, HEC 3 and HEC 6 are “extended clusters” that have luminosities typical of classical GCs but half-light radii several times larger ( $\geq 30$  pc) (Huxor et al. 2005; Mackey et al. 2006). This class of object has so far only been identified in M31, where 13 examples are currently known (Huxor et al. 2008); however, the faintest such objects are similar to the Milky Way’s Palomar clusters. The fact that two extended clusters lie within 6 kpc of And XVII is therefore extremely intriguing. Interestingly, HEC 6 lies close to the projected major axis of the dwarf, which may be indicative of the influence of tidal forces.

Figure 5 shows the distribution of dwarf satellites and GCs in the outer halo of M31. Only the GCs identified by Huxor et al. (2008) and Martin et al. (2006) are shown; however, these represent essentially all the confirmed clusters in the outer halo of M31 and have an average surface density of  $\approx 0.3$  deg $^{-2}$  beyond a radius of  $3^\circ$ . The group of three GCs within  $30'$  of And XVII is therefore quite unusual, with a probability of chance alignment of  $\approx 0.2\%$  (similar to the chance alignment of two of the GCs within  $16'$ ) and suggests that at least one of these objects may be associated with the dwarf. While several of the more luminous dwarf elliptical companions of M31 possess their own GC systems (see van den Bergh 2000), the only other M31 dSph with a GC projected within  $30'$  is And XIII. In this case, the GC lies  $\sim 15'$  from the center of the dwarf but very much in the foreground of M31 with a line-of-sight distance of  $631 \pm 58$  kpc (Martin et al. 2006). No published distance estimate is yet available for And XIII, though recently acquired Subaru imaging suggests it lies well beyond M31 (S. Chapman et al. 2008, in preparation). Within the Milky Way dSph population, only Fornax and Sagittarius possess their own GC systems; however, these are both considerably more luminous than And XVII. Radial velocities and deeper CMDs are required to test the reality of the association of And XVII

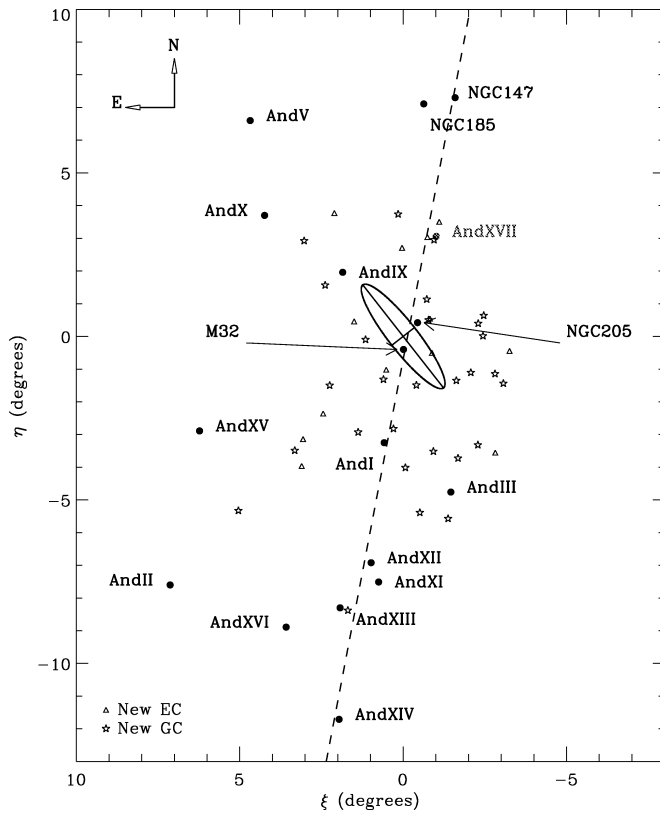


FIG. 5.—Map of the distribution of currently known dwarf satellites and outer globular clusters of M31. Compact clusters are represented by asterisks and extended clusters by triangles. The inner ellipse has a semimajor axis of 27 kpc and represents the bright disk of M31. More than half of the known satellites of M31 lie within  $\leq 50'$  of a radial vector that passes through the center of the galaxy and extends for  $\geq 19^\circ$  (dashed line). [See the electronic edition of the *Journal* for a color version of this figure.]

to the neighboring star clusters. If even one of these is confirmed, it would imply a specific frequency<sup>6</sup> of  $\sim 400$ , making And XVII very unusual compared to other low-luminosity gal-

<sup>6</sup>  $S_N = N_{GC} \times 10^{0.4(M_V + 15)}$ , where  $N_{GC}$  is the number of GCs and  $M_V$  is the host galaxy apparent magnitude (Harris & van den Bergh 1981).

axies, albeit with the caveat that this may still be consistent with a low overall probability of cluster formation in faint dwarf galaxies.

Another curious aspect of And XVII is its projected position on the sky. Patterns in the spatial distribution of satellites around host galaxies have long been a subject of much interest (e.g., Holmberg 1969), and previous analyses of the M31 system have been reported by Karachentsev (1996), McConnachie & Irwin (2006), and Koch & Grebel (2006). Given the rapid improvement in our census of M31 satellites in the last few years, even these recent studies are based on fairly incomplete samples. Considering projected positions on the sky alone, Majewski et al. (2007) have recently commented on the fact that many of the known satellites of M31 lie along a vector that connects And XIV to NGC 185 and NGC 147. Remarkably, And XVII is also consistent with this alignment. The result from a linear least-squares fit to the projected positions of NGC 147, NGC 185, And XVII, NGC 205, M32, And I, And XII, And XI, And XIII, and And XIV is shown in Figure 4. Of the 10 satellites (out of the 19 currently known), none deviate by more than  $50'$  ( $< 12$  kpc) from this vector over its  $19^\circ$  (260 kpc) extent. However, more accurate distances and further radial velocities are needed to test if this alignment could be a physical association rather than a chance projection effect, compounded by inhomogeneous survey depths.

Full analysis of the satellite distribution around M31 requires a comprehensive search in the remaining quadrants. We are currently using MegaCam on CFHT to survey an additional quadrant to a radius of  $\sim 150$  kpc. Further, the Pan-STARRS  $3\pi$  survey is due to get underway in late 2008; although only reaching depths comparable to the INT/WFC survey, it will do so over a much larger area. The prospects are therefore extremely promising for developing a more complete picture of the satellite and globular cluster system of M31.

We would like to thank the referee for their careful reading of the manuscript and helpful comments. A. M. N. F. and A. H. are supported by a Marie Curie Excellence Grant from the European Commission under contract MCEXT-CT-2005-025869. N. R. T. acknowledges financial support via an STFC Senior Research Fellowship.

## REFERENCES

- Armandroff, T. E., Davies, J. E., & Jacoby, G. H. 1998, *AJ*, 116, 2287  
 Armandroff, T. E., Jacoby, G. H., & Davies, J. E. 1999, *AJ*, 118, 1220  
 Bellazzini, M., Ferraro, F. R., & Pancino, E. 2001, *ApJ*, 556, 635  
 Belokurov, V., et al. 2006, *ApJ*, 647, L111  
 ———. 2007, *ApJ*, 654, 897  
 Choi, P. I., Guhathakurta, P., & Johnston, K. V. 2002, *AJ*, 124, 310  
 Ferguson, A. M. N., Gallagher, J. S., & Wyse, R. F. G. 2000, *AJ*, 120, 821  
 Ferguson, A. M. N., et al. 2002, *AJ*, 124, 1452  
 Harris, W. E., & van den Bergh, S. 1981, *AJ*, 86, 1627  
 Holmberg, E. 1969, *Ark. Astron.*, 5, 305  
 Huxor, A. P., et al. 2005, *MNRAS*, 360, 1007  
 ———. 2008, *MNRAS*, in press (arXiv:0801.0002)  
 Ibata, R., et al. 2001, *Nature*, 412, 49  
 ———. 2007, *ApJ*, 671, 1591  
 Irwin, M., & Hatzidimitriou, D. 1995, *MNRAS*, 277, 1354  
 Irwin, M., & Lewis, J. 2001, *NewA Rev.*, 45, 105  
 Irwin, M. J., et al. 2005, *ApJ*, 628, L105  
 ———. 2007, *ApJ*, 656, L13  
 Karachentsev, I. 1996, *A&A*, 305, 33  
 Karachentsev, I. D., & Karachentseva, V. E. 1999, *A&A*, 341, 355  
 Koch, A., & Grebel, E. K. 2006, *AJ*, 131, 1405  
 Komiyama, Y., et al. 2007, *AJ*, 134, 835  
 Kposov, S., et al. 2007, *ApJ*, 669, 337  
 Landolt, A. U. 1992, *AJ*, 104, 340  
 Mackey, A. D., et al. 2006, *ApJ*, 653, L105  
 Majewski, S. R., et al. 2007, *ApJ*, 670, L9  
 Martin, N. F., et al. 2006, *MNRAS*, 371, 1983  
 McConnachie, A. W., Arimoto, N., & Irwin, M. 2007, *MNRAS*, 379, 379  
 McConnachie, A. W., & Irwin, M. J. 2006, *MNRAS*, 365, 902  
 McConnachie, A. W., et al. 2004, *MNRAS*, 350, 243  
 ———. 2005, *MNRAS*, 356, 979  
 Morrison, H. L., et al. 2003, *ApJ*, 596, L183  
 Sakamoto, T., & Hasegawa, T. 2006, *ApJ*, 653, L29  
 Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, *ApJ*, 500, 525  
 Simon, J. D., & Geha, M. 2007, *ApJ*, 670, 313  
 van den Bergh, S. 1972, *ApJ*, 171, L31  
 ———. 2000, *The Galaxies of the Local Group* (Cambridge Astrophys. Ser. 35; Cambridge: Cambridge Univ. Press)  
 Walsh, S. M., Jerjen, H., & Willman, B. 2007, *ApJ*, 662, L83  
 Willman, B., et al. 2005a, *ApJ*, 626, L85  
 ———. 2005b, *AJ*, 129, 2692  
 Zucker, D. B., et al. 2004, *ApJ*, 612, L121  
 ———. 2006a, *ApJ*, 650, L41  
 ———. 2006b, *ApJ*, 643, L103  
 ———. 2007, *ApJ*, 659, L21